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CONTENTS

SOME ASPECTS OF ANIMAL MECHANISM[1]

IT is sometimes said that science lives too much in itself, but once a year it tries to remove that reproach. The British Association meeting is that annual occasion, with its opportunity of talking in wider gatherings about scientific questions and findings. Often the answers are tentative. Commonly questions most difficult are those that can be quite briefly put. Thus, "Is the living organism a machine?" "Is life the running of a mechanism?" The answer cannot certainly be as short as the question. But let us, in the hour before us, examine some of the points it raises. Of course for us the problem is not the "why" of the living organism but the "how" of its working. If we put before ourselves some aspects of this working we may judge some at least of the contents of the question. It might be thought that the problem is presented at its simplest in the simplest forms of life. Yet it is in certain aspects more seizable in complex animals than it is in simpler forms.

Our own body is full of exquisite mechanism. Many exemplifications could be chosen. There is the mechanism by which the general complex internal medium, the blood, is kept relatively constant in its chemical reaction, despite the variety of the food replenishing it and the fluctuating draft from and input into it from various organs and tissues. In this mechanism the kidney cells and the lung cells form two of the main sub-mechanisms. One part of the latter is the delicate mechanism linking the condition of the air at the bottom of the lungs with that particular part of the nervous system which manages the ventilation of the lungs. On that ventilation depends the

[1] Presidential address delivered at the Hull meeting of the British Association on September 6.

proper respiratory condition of the blood. The nervous center which manages the rhythmic breathing of the chest is so responsive to the respiratory state of the blood supplied to itself that, as shown by Drs. Haldane and Priestley some years ago, the very slightest increase in the partial pressure of carbon dioxide at the bottom of the lungs at once suitably increases the ventilation of the chest. Dovetailed in with this mechanism is yet another working for adjustment in the same direction. As the lung is stretched by each inbreath the respiratory condition of the nervous center, already attuned to the respiratory quality of the air in the lungs, sets the degree to which inspiration shall fill them ere there ensue the opposite movement of outbreath. All this regulation, although the nervous system takes part in it, is a mechanism outside our consciousness. Part of it is operated chemically; part of it is reflex reaction to a stimulus of mechanical kind, though as such unperceived. The example taken has been nervous mechanism. If, in the short time at our disposal, we confine our examples to the nervous system, we shall have the advantage that in one respect that system presents our problem possibly at its fullest.

To turn therefore to another example, mainly nervous. Muscles execute our movements; they also maintain our postures. This postural action of muscles is produced by nerve-centers which form a system more or less their own. One posture of great importance thus maintained is that of standing, the erect posture. This involves due cooperation of many separate muscles in many parts. Even in the absence of those portions of the brain to which consciousness is adjunct, the lower nerve-centers successfully bring about and maintain the cooperation of muscles which results in the erect posture; for example, the animal in this condition, if set on its feet, stands. It stands reflexly; more than that, it adjusts its standin posture to required conditions. If the pose of one of the limbs be shifted a compensatory shift in the other limbs is induced, so that stability is retained. A turn of the creature's neck sidewise and the body and limbs, of themselves, take up a fresh attitude appropriate to the side-turned head. Each particular pose of the neck telegraphs off to the limbs and body a particular posture required from them, and that posture is then maintained so long as the neck posture is maintained. Stoop the creature's neck and the forelimbs bend down as if to seek something on the floor. Tilt the muzzle upward and the forelimbs straighten and the hind limbs crouch as if to look at something on a shelf. Purely reflex mechanism provides all kinds of ordinary postures.

Mere reflex action provides these harmonies of posture. The nerve-centers evoke for this purpose in the required muscles a mild, steady contraction, with tension largely independent of the muscle length and little susceptible to fatigue. Nerve-fibers run from muscle to nerve-center, and by these each change in tension or length of the muscle is reported to the activating nerve-center. They say "tension rising, you must slacken," or conversely. There are also organs the stimulation of which changes with any change of their relation to the line of gravity. Thus, a pair of tiny water-filled bags is set one in each side of the skull and in each is a patch of cells endowed with a special nerve. Attached to hairlets of these cells is a tiny crystalline stone the pressure of which acts as a stimulus through them to the nerve. The nerve of each gravity-bag connects, through chains of nerve-centers, with the muscles of all the limbs and of one side of the neck. In the ordinary erect posture of the head, the stimulation by the two bags right and left is equal, because the two gravity-stones then lie symmetrically. The result, then, is a symmetrical muscular effect on the two sides of the body, namely, the normal erect posture. But the right and left bags are mirror pictures of each other. If the head incline to one side, the resulting slip, microscopic though it be, of the two stones on their nerve-patches makes the stimulation unequal. From that slip there results exactly the right unsymmetrical action of the muscles to give the unsymmetrical pose of limbs and neck required for stability. That is the mechanism dealing with limbs and trunk and neck. An additional one postures the head itself on the neck. A second pair of tiny gravity-bags, in

which the stones hang rather than press, are utilized. These, when any cause inclining the head has passed, bring the head back at once to the normal symmetry of the erect posture. These same bags also manage the posturing of the eyes. The eye contributes to our orientation in space; for example, to perception of the vertical. For this the eyeball, that is the retina, has to be postured normally, and the pair of little gravity-bags in the skull, which serve to restore the head posture, act also on the eyeball muscles. Whichever way the head turns, slopes, or is tilted, they adjust the eyeball's posture compensatingly, so that the retina still looks out upon its world from an approximately normal posture, retaining its old verticals and horizontals. As the head twists to the right the eyeball's visual axis untwists from the right. These reactions of head, eyes and body unconsciously take place when a bird wheels or slants in flight or a pilot stalls or banks his areoplane; and all this works itself involuntarily as a pure mechanism.

True, in such a glimpse of mechanism what we see mainly is how the machinery starts and what finally comes out of it; of the intermediate elements of the process we know less. Each insight into mechanism reveals more mechanism still to know. Thus, scarcely was the animal's energy balance in its bearing upon food intake shown comfortably to conform with thermodynamics than came evidence of the so-called "vitamins"—evidence showing an unsuspected influence on nutrition by elements of diet taken in quantities so small as to make their mere calorie value quite negligible; thus, for the growing rat, to quote Professor Harden, a quantity of vitamin A of the order of one five-hundredths milligram a day has potent effect. Again, as regards sex determination, the valued discovery of a visible distinction between the nuclear threads of male and female brings the further complexity that, in such cases, sex extends throughout the whole body to every dividing cell. Again, the asssociation of hereditary unit-factors, such as body color or shape of wing, to visible details in the segmenting nucleus seemed to simplify by epitomizing. But further insight tends to trace the inherited unit character not to the chromosome itself, but to balance of action between the chromosome group. As with the atom in this heroic age of physicists, the elementary unit once assumed simple proves, under further analysis, to be itself complex. Analysis opens a vista of further analysis required. Knowledge of muscle contraction has, from the work of Fletcher and Hopkins on to Hill, Hartree, Meyerhof and others, advanced recently more than in many decades heretofore. The engineer would find it difficult to make a motive machine out of white of egg, some dissolved salts, and thin membrane. Yet this is practically what nature has done in muscle, and obtained a machine of high mechanical efficiency. Perhaps human ingenuity can learn from it. One feature in the device is alternate development and removal of acidity. The cycle of contraction and relaxation is traced to the production of lactic acid from glycogen and its neutralization chiefly by alkaline proteins; and physically to an admirably direct transition from chemical to mechanical effect. What new steps of mechanism all this now opens!

But knowledge, while making for complexity, makes also for simplification. There seems promise of simplification of the mechanism of reflex action. Reflex action with surprising nicety calls into play just the appropriate muscles, and adjusts them in time and in the suitable grading of their strength of pull. The moderating as well as the driving of muscles is involved. Also the muscles have to pass from the behest of one stimulus to that of another, even though the former stimulus still persist. For these gradings, coadjustments, restraints, and shifts, various separate kinds of mechanism were assumed to exist in the nerve-centers, although of the nature of such mechanisms little could be said. Their processes were regarded as peculiar to the nerve-centers and different from anything that the simple fibers of nerve-trunks outside the centers can produce. We owe to Lucas and Adrian the demonstration that, without any nerve-center whatever, an excised nerve-trunk with its muscle attached can be brought to yield, besides conduction of nerve impulses, the grading of them. That is remarkable, because the

impulse is not gradable by grading the strength of the stimulus. The energy of the impulse comes not from the stimulus, but from the fiber itself. But Lucas and Adrian have shown, however, that it is gradable in another way. Though the nerve impulse is a very brief affair—it lasts about one thousandths second at any one point of the nerve—it leaves behind it in the nerve-fiber a short phase during which the fiber cannot develop a second impulse. Then follows rapid but gradual recovery of the strength of impulse obtainable from the fiber. That recovery may swing past normal to supernormal before returning finally to the old resting state. Hence, by appropriately timing the arrival of a second impulse after a first, that second impulse may be extinguished, reduced, increased or transmitted without alteration. This property of grading impulses promises a complete key to reflex action if taken along with one other. The nervous system, including its centers, consists of nothing but chains of cells and fibers. In these chains the junctions of the links appear to be points across which a large impulse can pass, though a weak one will fail. At these points the grading of impulses by the interference process just outlined can lead, therefore, to narrowing or widening their further distribution, much as in a railway system the traffic can be blocked or forwarded, condensed or scattered. Thus the distribution and quantity of the muscular effect can be regulated and shifted not only from one muscle to another, but in one and the same muscle it can be graded by adding to or subtracting from the number of fibers activated within that muscle. As pointed out by Professor Alexander Forbes, it may be, therefore, that the nerve impulse is the one and only reaction throughout the whole nervous system, central and peripheral,—trains of impulses colliding and over-running as they travel along the conductive network. In this may lie the secret of the coordination of reflexes. The nerve-center seems nothing more than a meeting-place of nerve-fibers, its properties but those of impulses in combination. Fuller knowledge of the mechanism of the nervous impulse, many of the physical properties of which are now known, a reaction which can be studied in the simplest units of the nervous system, thus leads to a view of nervous function throughout the system much simpler than formerly obtained.

Yet for some aspects of nervous mechanism the nerve impulse offers little or no clue. The fibers of nerve-trunks are, perhaps, of all nerve-structures those that are best known. They constitute, for example, the motor nerves of muscle and the sensory nerves of the skin. They establish their ties with muscle and skin during embryonic life and maintain them practically unaltered throughout the individual's existence, growing no further. If severed, say, by a wound, they die for their whole length between the point of severance and the muscle or skin they go to. Then at once the cut ends of the nerve-fibers start regrowing from the point of severance, although for years they have given no sign of growth. The fiber, so to say, tries to grow out to reach to its old far-distant muscle. There are difficulties in its way. A multitude of non-nervous repair cells growing in the wound spin scar tissue across the new fiber's path. Between these alien cells the new nerve-fiber threads a tortuous way, avoiding and never joining any of them. This obstruction it may take many days to traverse. Then it reaches a region where the sheath-cells of the old dead nerve-fibers lie altered beyond ordinary recognition. But the growing fiber recognizes them. It joints them and, tunneling through endless chains of them, arrives finally, after weeks or months, at the wasted muscle-fibers which seem to have been its goal, for it connects with them at once. It pierces their covering membranes and reforms with their substance junctions of characteristic pattern resembling the original that had died weeks or months before. Then its growth ceases, abruptly, as it began, and the wasted muscle recovers and the lost function is restored.

Can we trace the causes of this beneficent yet so unaccountable reaction? How is it that severance can start the nerve re-growing. How does the nerve-fiber find its lost muscle microscopically miles away? What is that mechanism that drives and guides it? Is it a chemotaxis like that of the antherozooid in the botanical experiment drawn towards the focus of the

dissolved malic acid? If so, there must be a marvelously arranged play of intricate sequences of chemically attractive and repellent substances dissolved suitably point to point along the tissue. It has recently been stated that the nerve-fiber growing from a nerve-cell in a nutrient field of graded electrical potential grows strictly by the axis of the gradient. Some argue for the existence of such potential gradients in the growing organism. Certainly nerve regeneration seems a return to the original phase of growth, and pieces of adult tissue removed from the body to artificial nutrient media in the laboratory take on vigorous growth. Professor Champy describes how epithelium that in the body is not growing, when thus removed starts growing. If freed from all fibrous tissue, its cells not only germinate, but, as they do so, lose their adult specialization. In nerve regeneration the nerve-sheath cells, and to some extent the muscle-cells which have lost their nerve-fiber, lose likewise their specialized form, and regain it only after touch with the nerve-cell has been re-established. So similarly epithelium and its connective tissue cultivated outside the body together both grow and both retain their specialization. The evidence seems to show that the mutual touch between the several cells of the body is decisive of much in their individual shaping and destiny. The severance of a nerve-fiber is an instance of the dislocation of such a touch. It recalls well-known experiments on the segmenting egg. Destruction of one of the two halves produced by the first segmentation of the egg results in a whole embryo from the remaining half-egg; but if the two blastomeres, though ligated, be left side by side, each then produces a half-embryo. Each half-egg *can* yield a whole embryo, but is restrained by the presence of the twin cell to yielding but a half embryo. The nerve severance seems to break a mutual connection which restrained cell growth and maintained cell differentiation.

It may be said that the nerve-sheath cells degrade because the absence of transmission of nerve impulses leaves their fiber functionless. But they do not degrade in the central nerve-piece, although impulses no longer pass along the afferent fibers. This mechanism of reconstruction seems strangely detached from any direct performance of function. The sprouting nerve-fibers of a motor nerve with impulses for muscular contraction can by misadventure take their way to denervated skin instead of muscle. They find the skin-cells the nerve-fibers of which have been lost, and on these they bud out twigs, as true sensory fibers would do. Then, seemingly satisfied by so doing, they desist from further growth. The sense-cells, too, after this misunion, regain their normal features. But this joining of motor nerve-fiber with sense-cell is functionless, and must be so because the directions of functional conduction of the two are incompatible. Similarly a regenerating skin-nerve led down to muscle makes its union with muscle instead of skin, though the union is a functional misfit and can not subserve function. Marvelous though nerve regeneration be its mechanism seems blind. Its vehemence is just as great after amputation, when the parts lost can of course never be re-reached. Its blindness is sadly evident in the suffering caused by the useless nerve-sprouts entangled in the scar of a healing or healed limb-stump.

There is a great difference, however, between the growth of such regeneration and the growth impulse in pieces of tissue isolated from the body and grown in media outside. With pure cultures, in the latter case, Professor Champy says the growth recalls in several features that of malignant tumors, for example, multiplication of cells unaccompanied by formation of a specialized adult tissue. A piece of kidney cultivated outside the body de-differentiates, to use his term, into a growing mass unorganized for renal function. But with connective-tissue cells added even breast-cancer epithelium will in cultivation grow in glandular form. New ground is being broken in the experimental control of tissue growth. The report of the Imperial Cancer Research Fund mentions that in cultivation outside the body malignant cells present a diffculty that normal cells do not. To the malignant cells the nutrient soil has to be renewed more frequently, because they seem rapidly to make the soil in which they grow poisonous to themselves,

though not to normal cells. The following of all clues of difference between the mechanism of malignant growth and of normal is fraught with importance which may be practical as well as theoretical.

The regenerating nerve rebuilds to a plan that spells for future function, but throughout all its steps prior to the time when it actually reaches the muscle or skin, no actual performance of nerve-function can take place. What is constructed is functionally useless until the whole is complete. So similarly with much of the construction of the embryo in the womb for purposes of a different life after emergence from the womb; of the lung for air-breathing after birth; of the reflex contraction in the fœtal child of the eyelids to protect the eye long before the two eyelids have been separated, let alone ere hurt or even light can reach it; of the butterfly's wing within the chrysalis for future flight. The nervous system in its repair, as in its original growth, shows us a mechanism working through phases of non-functioning preparation in order to forestall and meet a future function. It is a mechanism against the seeming prescience of which is to be set its fallibility and its limitations. The "how" of its working is at present chiefly traceable to us in the steps of its results rather than in comprehension of its intimate reactions; as to its mechanism, perhaps the point of chief import for us here is that those who are closest students of it still regard it as a mechanism. If "to know" be "to know the causes" we must confess to want of knowledge of how its mechanism is contrived.

If we knew the whole "how" of the production of the body from egg to adult, and if we admit that every item of its organic machinery runs on physical and chemical rules as completely as do inorganic systems, will the living animal present no other problematical aspect? The dog, our household friend—do we exhaust its aspects if in assessing its sum-total we omit its mind? A merely reflex pet would give little pleasure even to the fondest of us. True, our acquaintance with other mind than our own can only be by inference. We may even hold that mind as an object of study does not come under the rubric of natural science at all. But this association has its section of psychology, and my theme of to-night was chosen partly at the suggestion of a late member of it, Dr. Rivers, the loss of whom we all deplore. As a biologist he viewed mind as a biological factor. Keeping mind and body apart for certain analytic purposes must not allow us to forget their being set together when we assess as a whole even a single animal life.

Taking as manifestations of mind those ordinarily received as such, mind does not seem to attach to life, however complex, where there is no nervous system, nor even where that system, though present, is little developed. Mind becomes more recognizable the more the nerve-system is developed; hence the difficulty of the twilit emergence of mind from no mind, which is repeated even in the individual life history. In the nervous system there is what is termed localization of function—relegation of different works to the system's different parts. This localization shows mentality, in the usual acception of that term, not distributed broadcast throughout the nervous system, but restricted to certain portions of it; for example, among vertebrates to what is called the forebrain, and in higher vertebrates to the relatively newer parts of that forebrain. Its chief, perhaps its sole, seat is a comparatively modern nervous structure superposed on the non-mental and more ancient other nervous parts. The so-to-say mental portion of the system is placed so that its commerce with the body and the external world occurs only through the archaic non-mental remainder of the system. Simple nerve impulses, their summations and interferences, seem the one uniform office of the nerve-system in its non-mental aspect. To pass from a nerve impulse to a psychical event, a sense-impression, percept, or emotion is, as it were, to step from one world to another and incommensurable one. We might expect, then, that at the places of transition from its non-mental to its mental regions the brain would exhibit some striking change of structure. But it is not so; in the mental parts of the brain there is nothing but the same old structural elements, set end to end, suggesting the one function of the transmission and collision of nerve impulses. The structural inter-connections are richer, but that is merely a quantitative change.

I do not want, and do not need, to stress our inability at present to deal with mental actions in terms of nervous actions, or *vice versa.* Facing the relation borne in upon us as existent between them, however, may we not gain some further appreciation of it by reminding ourselves even briefly of certain points of contact between the two? Familiar as such points are, I will mention rather than dwell upon them.

One is the so-called expression of the emotions. The mental reaction of an emotion is accompanied by a nervous discharge which is more or less characteristic for each several type of emotion, so that the emotion can be read from its bodily expression. This nervous discharge is involuntary, and can affect organs, such as the heart, which the will can not reach. Then there is the circumstance that the peculiar ways and tricks of the nervous machinery as revealed to us in the study of mere reflex reactions repeat themselves obviously in the working of the machinery to which mental actions are adjunct. The phenomenon of fatigue is common to both, and imposses similar disabilities on both. Nervous exhaustion and mental exhaustion mingle. Then, as offset against this disability, there exists in both the amenability to habit formation, mere repetition within limits rendering a reaction easier and readier. Then, and akin to this, is the oft-remarked trend in both for a reaction to leave behind itself a trace, an engram, a memory, the reflex engram, and the mental memory.

How should inertia and momentum affect non-material reactions? Quick though nervous reactions are, there is always easily observed delay between delivery of stimulus and appearance of the nervous end effect; and there is always the character that a reaction once set in motion does not cease very promptly. Just the same order of lag and overrun, of want of dead-beat character, is met in sense-reactions. The sensation outlives the light which evoked it, and the stronger the reaction the longer the sensation persists. Similarly the reflex after-discharge persists after the stimulus is withdrawn and subsides more slowly the stronger the reaction. The times in both are of the same order. Again, a reflex act which contracts one muscle commonly relaxes another. Even so, with rise of sensation in one part of the visual field commonly occurs lapse of sensation in another. The stoppage is in both by inhibition, that is to say, active. Then again, two lights of opposite color falling simultaneously and correspondingly on the two retinæ will, according to their balance, fuse to an intermediate tint or see-saw back and forth between the one tint and the other. Similarly a muscle impelled by two reflexes, one tending to contract it, the other to relax it, will, according to the balance of the reflexes, respond steadily with an intensity which is a compromise between the two, or see-saw rhythmically from extreme to extreme of the two opposite influences.

Reflex acts commonly predispose to their opposites; thus the visual impression of one color predisposes to that of its opposite. Again, the *position* of the stimulated sensual point acts on the mind—hence the light seen or the pain felt is referred to some locus in the mind's space-system. Similarly the reflex machinery directs, for example, the limb it moves towards the particular spot stimulated. Such spots in the two processes, mental and non-mental, correspond.

Characteristic of the nervous machinery is its arrangement in what Hughlings Jackson called "levels," the higher levels standing to the lower not only as drivers but also as restrainers. Hence in disease underaction of one sort is accompanied by overaction of another. Thus in the arm affected by a cerebral stroke, besides loss of willed—that is higher level—power in the finger muscles, there is in other muscles involuntary overaction owing to escape of lower centers from control by the higher which have been destroyed. Similarly with the sensory effects; of skin sensations some are painful and some not, for example, touch. The seat of the latter is of higher level, cortical; of the former lower, sub-cortical. When cerebral disease breaks the path between the higher and the underlying level a result is impairment of touch sensation but heightening of pain sensation in the affected part. The sensation of touch, as Dr. Head says, restrains that of pain.

Thus features of nervous working resemble over and over again mental activities. Is it mere metaphor, then, when we speak of mental

attitudes as well as bodily? Is it mere analogy to liken the warped attitude of the mind in a psychoneurotic sufferer to the warped attitude of the body constrained by an internal potential pain? Again, some mental events seem spontaneous; in the nervous system some impulses seem generated automatically from within.

It may be said of all these similarities of time-relation and the rest between the ways of the nervous system and such simpler ways of mind as I here venture on, that they exist because the operations of the mental part of the nervous system communicate with the exterior only through the non-mental part as gateway, and that there the features of the nerve-machinery are impressed on the mind's working. But that suggestion does not take into account the fact that the higher and more complex the mental process, the longer the time-lag, the more incident the fatigue, the more striking the memory character, and so on.

All this similarity does but render more succinct the old enigma as to the nexus between nerve impulse and mental event. In the proof that the working of the animal mechanism conforms with the first law of thermodynamics is it possible to say that psychical events are evaluated in the balance sheet drawn up? On the other hand, Mr. Barcroft and his fellow-observers in their recent physiological exploration of life on the Andes at 14,200 feet noted that their arithmetic as well as their muscles were at a disadvantage; the low oxygen pressure militated against both. Indeed, we all know that a few minutes without oxygen, or few more with chloroform, and the psychical and the nervous events will lapse together. The nexus between the two sets of events is strict, but for comprehension of its nature we still require, it seems, comprehension of the unsolved mystery of the "how" of life itself. A shadowy bridge between them may lie perhaps in the reflection that for the observer himself the physical phenomena he observes are in the last resort psychical.

The practical man has to accept nervous function as a condition for mental function without concerning himself about ignorance of their connection. We know that with structural derangement or destruction of certain parts of the brain goes mental derangement or defect, while derangement or destruction of other parts of the nervous system is not so accompanied. Decade by decade the connection between certain mental performances and certain cerebral regions becomes more definite. Certain impairments of ideation as shown by forms of incomprehension of language or of familiar objects can help to diagnose for the surgeon that part of the brain which is being compressed by a tumor, and the tumor gone the mental disabilities pass. Similarly those who, like Professor Elliot Smith and Sir Arthur Keith, recast the shape of the cerebrum from the cranial remains of prehistoric man, can outline for us something of his mentality from examination of the relative development of the several brain regions, using a true and scientific phrenology.

Could we look quite naïvely at the question of a seat for the mind within the body we might perhaps suppose it diffused there, not localized in any one particular part at all. That it is localized and that its localization is in the nervous system—can we attach meaning to that fact? The nervous system is that bodily system the special office of which, from its earliest appearance onward throughout evolutionary history, has been more and more to weld together the body's component parts into one consolidated mechanism reacting as a unity to the changeful world about it. More than any other system it has constructed out of a collection of organs an individual of unified act and experience. It represents the acme of accomplishment of the integration of the animal organism. That it is in this system that mind, as we know it, has had its beginning, and with the progressive development of the system has developed step for step, is surely significant. So it is that the portion in this system to which mind transcendently attaches is exactly that where are carried to their highest pitch the nerve-actions which manage the individual as a whole, especially in his reactions to the external world. There, in the brain, the integrating nervous centers are themselves further compounded, inter-connected, and re-combined for unitary functions. The cortex of the fore-

brain is the main seat of mind. That cortex with its twin halves corresponding to the two side-halves of the body is really a single organ knitting those halves together by a still further knitting together of the nervous system itself. The animal's great integrating system is there still further integrated and this supreme integrator is the seat of all that is most clearly inferable as the animal's mind. As such it has spelt biological success to its possessors. From small beginnings it has become steadily a larger and larger feature of the nervous system, until in adult man the whole remaining portion of the system is relatively dwarfed by it. It is not without significance, perhaps, that in man this organ, the brain cortex, bifid as it is, shows unmistakable asymmetry. Man is a tool-using animal, and tools demand asymmetrical, though attentive and therefore unified, acts. A nervous focus unifying such motor function will, in regard to a laterally bipartite organ, tend more to one half or the other and in man's cerebrum the preponderance of one half, namely, the left, over the other may be a sign of unifying function.

It is to the psychologist that we must turn to learn in full the contribution made to the integration of the animal individual by mind. But each of us can recognize, without being a professed psychologist, one achievement in that direction which mental endowment has produced. Made up of myriads of microscopic cell-lives, individually born, feeding and breathing individually within the body, each one of us nevertheless appears to himself a single entity, a unity experiencing and acting as one individual. In a way the more far-reaching and many-sided the reactions of which a mind is capable the more need, as well as the more scope, for their consolidation to one. True, each one of us is in some sense not one self, but a multiple system of selves. Yet how closely those selves are united and integrated to one personality. Even in those extremes of so-called double personality one of their mystifying features is that the individual seems to himself at any one time wholly either this personality or that, never the two commingled. The view that regards hysteria as a mental dissociation illustrates the integrative trend of the total healthy mind. Circumstances can stress in the individual some, perhaps lower, instinctive tendency that conflicts with what may be termed his normal personality. This latter, to master the conflicting trend, can judge it in relation to his main self's general ethical ideals and duties to self and the community. Thus intellectualizing it, he can destroy it or consciously subordinate it to some aim in harmony with the rest of his personality. By so doing there is gain in power of will and in personal coherence of the individual. But if the morbid situation be too strong or the mental self too weak, instead of thus assimilating the contentious element the mind may shun and, so to say, endeavor to ignore it. That way lies danger. The discordant factor escaped from the sway of the conscious mind produces stress and strain of the conscious self; hence, to use customary terminology, dissociation of the self sets in, bringing in its train those disabilities, mental or nervous or both, which characterize the sufferer from hysteria. The normal action of the mind is to make up from its components one unified personality. When we remember the manifold complexity of composition of the human individual, can we observe a greater example of solidarity of working of an organism than that presented by the human individual, intent and concentrated, as the phrase goes, upon some higher act of strenuous will? Physiologically the supreme development of the brain, psychologically the mental powers attaching thereto, seem to represent from the biological standpoint the very culmination of the integration of the animal organism.

The mental attributes of the nervous system would be, then, the coping-stone of the construction of the individual. Surveyed in their broad biological aspect, we see them carrying integration even further still. They do not stop at the individual; they proceed beyond the individual; they integrate, from individuals, communities. When we review, so far as we can judge it, the distribution of mind within the range of animal forms, we meet two peaks of its development—one in insect life, the other in the vertebrate, with its acme finally in man. True, in the insect the type of mind is not

rational but instinctive, whereas at the height of its vertebrate development reason is there as well as instinct. Yet in both one outcome seems to be the welding of individuals into societies on a scale of organization otherwise unattained. The greatest social animal is man and the powers that make him so are mental; language, tradition, instinct for the preservation of the community, as well as for the preservation of the individual, reason actuated by emotion and sentiment, and controlling and welding egoistic and altruistic instincts into one broadly harmonious, instinctive-rational behavior. Just as the organization of the cell-colony into an animal individual receives its highest contribution from the nervous system, so the further combining of animal individuals into a multi-individual organism, a social community, merging the interests of the individual in the interests of the group, is due to the nervous system's crowning attributes, the mental. That this integration is still in process, still developing, is obvious from the whole course of human pre-history and history. The biological study of it is essentially psychological; it is the scope and ambit of social psychology. Not the least interesting and important form of social psychology is that relatively new one, dealing with the stresses and demands that organized industry makes upon the individual as a unit in the community of our day and with the readjustments it asks from that community.

To resume, then, we may, I think, conclude that in some of its aspects animal life presents to us mechanism the "how" of which, despite many gaps in our knowledge, is fairly explicable. Of not a few of the processes of the living body, such as muscular contraction, the circulation of the blood, the respiratory intake and output by the lungs, the nervous impulse and its journeyings, we may fairly feel, from what we know of them already, that further application of physics and chemistry will furnish a competent key. We may suppose that in the same sense as we can claim to-day that the principles of a gas-engine or an electromotor are comprehensible, so will the bodily working in such mechanisms be understood by us, and indeed are largely so already. It may well be possible to understand the principle of a mechanism which we have not the means or skill ourselves to construct; for example, we cannot construct the atoms of a gas-engine.

Turning to other aspects of animal mechanism, such as the shaping of the animal body, the conspiring of its structural units to compass later functional ends, the predetermination of specific growth from egg to adult, the predetermined natural term of existence, these and their intimate mechanism, we are, it seems to me, despite many brilliant inquiries and inquirers, still at a loss to understand. The steps of the results are known, but the springs of action still lie hidden. Then again, the "how" of the mind's connexion with its bodily place seems still utterly enigma. Similarity or identity in time-relations and in certain other ways between mental and nervous processes does not enlighten us as to the actual nature of the connexion existing between the two. Advance in biological science does but serve to stress further the strictness of the nexus between them.

Great differences of difficulty therefore confront our understanding of various aspects of animal life. Yet the living creature is fundamentally a unity. In trying to make the "how" of an animal existence intelligible to our imperfect knowledge we have, for purposes of study, to separate its whole into part-aspects and part-mechanisms, but that separation is artificial. It is as a whole, a single entity, that the animal, or for that matter the plant, has finally and essentially to be envisaged. We cannot really understand one part without the other. Can we suppose a unified entity which is part mechanism and part not? One privilege open to the human intellect is to attempt to comprehend, not leaving out of account any of its properties, the "how" of the living creature as a whole. The problem is ambitious, but its importance and its reward are all the greater if we seize and attempt the full width of its scope. In the biological synthesis of the individual it is concerned with mind. It includes examination of man himself as acting under a biological trend and process which is

combining individuals into a multi-individual organization, a social organism surely new in the history of the world. This biological trend and process is constructing a social organism the cohesion of which depends mainly on a property developed so specifically in man as to be, broadly speaking, his alone, namely, a mind actuated by instincts but instrumented with reason. Man, often Nature's rebel, as Sir Ray Lankester has luminously said, can, viewing this great supra-individual process, shape his courses conformably with it even as an individual, feeling that in this case to rebel would be to sink lower rather than to continue his own evolution upward.

C. S. Sherrington

CAN WASTE OF MENTAL EFFORT BE AVOIDED

One of the most startling phenomena in the history of science and invention is the lack of economy of mental effort. As a rule the great discoveries in science have not been made once, but have been repeated several times. It is as though engineers had built several Panama canals when only one was needed, thereby producing financial waste. At the recent death of Alexander Graham Bell the daily press reminds us that he invented the telephone. But he was not the only one who accomplished this. On the very day that Bell patented his telephone, Elisha Gray applied for a patent for an instrument of similar kind. At an earlier date Phillip Reis sent a speaking machine to the emperor of Russia. The same is true in the invention of the telegraph. No historian of science can give Samuel Morse exclusive credit. Before him, Joseph Henry at Albany, by the attraction of an electromagnet, produced audible signals at a distance. Gauss and Weber sent messages by an electromagnetic device over wires connecting the Observatory and Physical Cabinet at Göttingen. The mental effort of inventing the telegraph and telephone was made, not once, but several times.

These are only two of the numerous illustrations which might be given of duplication in applied science. In pure science the situation is even worse. Waste of effort through repetition occurred in the discovery of the laws of gases, Ohm's law in electricity, the principle of the conservation of energy, logarithms, determinants, J. W. Gibb's equilibrium of chemical systems and Mendel's law. The full accounts of reproduction of scientific discovery and invention would fill a large book. The waste of gray matter has resembled the prodigality of the pine-tree which produces millions of pollen particles for every new plant that is actually started.

It may be argued that the waste occurs only in the records of centuries which are passed, that the number of scientific journals has now increased so greatly that scientific results can be published promptly. As a matter of fact, the greater number of journals has not brought effective relief. The danger of unnecessary repetition is still with us. Not only is the army of scientific workers tremendously augmented, so that even now the editorial desks are overloaded with able manuscripts and publication is not so prompt as some suppose, but the long list of scientific journals has greatly augmented the labor on the part of any one worker to ascertain what new results have been reached in his particular field of activity. Paradoxical as it may seem, the publications themselves, by their great mass, clog the worker's efforts to find what he desires.

It is still true that investigators are frequently unacquainted with results already reached by others. And so it frequently happens that the best brains are exercised to the utmost in discovering things already discovered by others. Creative genius is rare. There are in a generation few cubic decimeters of brains in a nation, capable of materially advancing science, and yet history shows that in the past a large part of these precious cubic decimeters of gray matter has been expended upon needless repetition.

Is it not possible to improve on the present wasteful methods of conducting research? There is indeed need of persistence in the endeavor that

> No subtle, bright and novel thought
> In this wide world shall come to naught;
> No germ of purest ray serene
> Shall scintillate by us unseen.